

The Cluster Temperature Function at High Redshift

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Abstract.

We take advantage of the biggest cosmological simulation to date for a critical CDM universe in order to test robustness of the cluster mass function on a range of masses much wider than tested before. On the high mass end our results show an excess of hot clusters and a milder evolution compared to the analytical predictions based on the Press & Schechter formula. These features must be properly taken into account in deriving the cluster X-ray temperature function at moderate and high redshifts. On a general basis, the reduced negative evolution in the number of hot clusters could alleviate the discrepancies between the predictions for critical universes and incoming data, which instead seem to favour low Ω_0 .

1. Introduction

The crucial link between the initial density perturbations in the linear stage and the present day high contrast objects is made by the non linear gravitational dynamics. This can be followed in full detail only by very time consuming N-body simulations. To achieve this, several parallel N-body algorithms have been developed recently. Meanwhile, analytical tools has been checked on these numerical results, leading to the wide popularity of the Press & Schechter (1974, PS) formula as a fair description of both the shape and evolution of the cluster mass function $N(M)$. A detailed description of the PS statistics with an understanding of its dynamical basis can be found in Bond et al. (1991). Its main advantage compared to other analytical methods lies in its simplicity and applicability to many different cosmologies.

The agreement between PS and the N-body is, at some level, very surprising because the PS formula is based entirely on the linear theory, neglecting all the non linear effects which are expected to be important. Here we just recall its essential ingredients: the dispersion $\sigma(M)$ of the linear perturbation field; the linear growth factor $D(z)$; the linear collapse threshold δ_c . The latter is generally set to the top-hat value $\delta_c = 1.686$.

Thus all the complex dynamical processes of formation and evolution of virialized objects are condensed into two numbers: δ_c and $D(z)$. In a critical

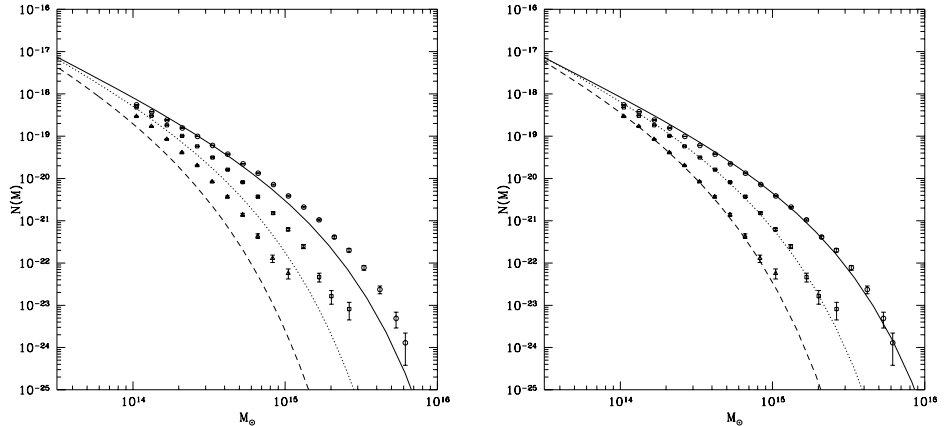


Figure 1. On panel a) the N-body mass function (points) is compared with the canonical PS prediction with $\delta_c = 1.686$ (lines) at different redshifts: 0 (circles, continuous line), 0.5 (squares, dotted line), 1 (triangles, dashed line). On panel b) the N-body mass function with the PS prediction after changing δ_c to the best fit value δ_{eff} at each output ($N(M)$ is in $M_\odot^{-1} \text{ Mpc}^{-3}$).

universe the strong dependence $D(z) \propto (1+z)^{-1}$ reflects in a strong negative evolution at higher z for $N(M)$.

To assess the reliability of the PS predictions of cluster temperature distribution at high z , we first test both shape and evolution of the mass function in the case of a critical CDM universe.

2. Results for a Critical CDM

The simulations were run using a by a parallel treecode which allows periodic boundary conditions and individual time steps (Quinn et al. 1997). The volume simulated was $500h^{-1}\text{Mpc}$ with $H_0 = 50 \text{ km/sec/Mpc}$, $\Omega_0 = 1$ and $\sigma_8 = 0.7$. We used 360^3 particles, almost 47 million. We adopt the CDM power spectrum given in Bardeen et al. (1986).

In figure 1 a) we show the resulting mass distribution at three output redshifts 0, 0.5 and 1. The rapid evolution is already evident at moderate redshifts. Clearly the local mass function is underestimated for $M > 10^{15} M_\odot$ with respect to the canonical ($\delta_c = 1.686$) PS prediction. The discrepancies grow at higher redshift, and at $z = 1$ the number density is underestimated by a factor ≥ 3 for $M > 3 \cdot 10^{14} M_\odot$.

We perform a χ^2 test on the high mass end to evaluate the best fit parameter $\delta_{eff}(z)$ at each output in redshift. We show that δ_{eff} is clearly always smaller than the top-hat value 1.686, and it is significantly lower for higher redshift, though the decrement is only 6% at $z \sim 1$. This dependence can be approximated by a simple power law: $\delta_{eff}(z) = 1.48(1+z)^{-0.06}$. The N-body

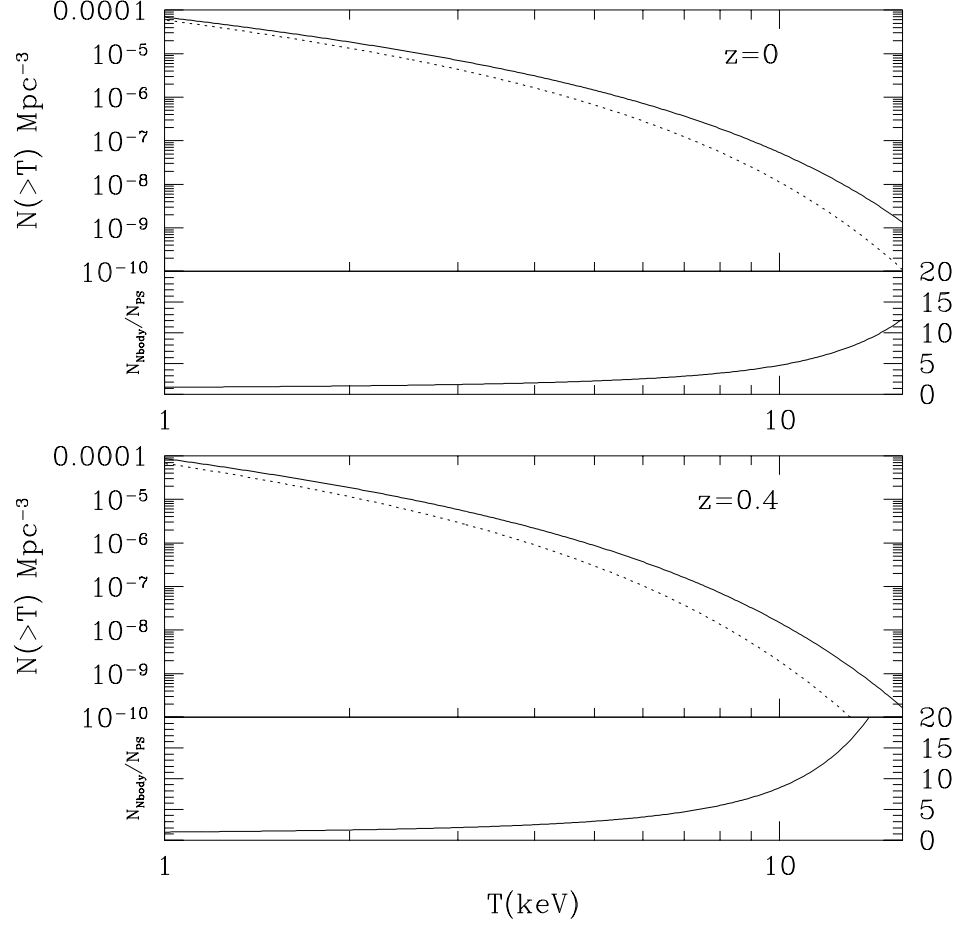


Figure 2. The cumulative temperature function $N(> T)$ in a critical CDM universe at $z = 0$ and $z = 0.4$ (continuous lines), compared with the canonical PS predictions (dotted lines). In the lower boxes, the ratio of the N-body cluster density to PS prediction is shown. Discrepancies become important at $z \geq 0.4$ and $kT \geq 7$ keV.

mass function, plotted against the PS mass function with the best fit value δ_{eff} instead of δ_c at each z , is shown in figure 1 b).

We carefully match our data with previous works, which often claimed a very good agreement with the PS predictions (see, for a recent work, Eke et al. 1996). Such previous simulations explored a smaller mass range than the one available to us, with poorer statistics and larger uncertainties. On the same range and with the same statistics, we would claim good agreement with both the analytical PS prediction and previous numerical works.

3. The Cluster temperature distribution

Under the assumption of dynamical equilibrium, the temperature of the intra-cluster plasma is directly linked to the depth of the potential wells. The relation $T(M)$ can be easily recovered in the case of a simple spherical collapse model (see, e.g., Eke et al. 1996). This relation has been successfully tested against N-body hydrodynamical simulations (Navarro et al. 1995).

The evolution of the temperature distribution is very sensitive to the adopted model of structures formation, and its evolution at moderate redshift is considered a crucial test for CDM models (for recent works in this field see Mathiesen & Evrard 1997, Kitayama & Suto 1997).

In figure 2 the local cumulative function $N(> T)$ is plotted for the canonical PS (dotted line) and numerical prediction (continuous line). While discrepancies are less than a factor 3 for $kT \leq 8$ keV, they become significant at $z = 0.4$, where the N-body simulation predicts significant excess above $kT \simeq 7$ keV. This not only points out a severe failure of the PS approach, but makes it even more difficult for a high normalization (e.g. based on COBE) CDM spectrum to satisfy constraints on cluster scales. On the other hand, the reduced negative evolution in the number of hot clusters could alleviate the discrepancy between the expected abundances in critical universes and incoming data, which instead seem to favour low Ω_0 (Henry 1997). We are extending the analysis to other CDM spectra in order to address this point.

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References

- Bardeen, J.M., Bond, J.R., Kaiser, N., & Szalay, A.S. 1986, ApJ, 305, 15
- Bond, J.R., Cole, S., Efstathiou, G., & Kaiser, N. 1991, ApJ 379, 440
- Eke, R., Cole, S., & Frenk, C. 1996, MNRAS 282, 263
- Henry, J.P., 1997, ApJL, 489, 1
- Kitayama, T., & Suto, Y., ApJ, in press [astro-ph/9792017]
- Mathiesen, B., & Evrard, A.E. 1997, MNRAS, in press [astro-ph/9703176]
- Navarro, J.F., Frenk, C.S., White, S.D.M., 1995, MNRAS, 275, 730
- Press, W.H., & Schechter, P. 1974, ApJ, 187, 425
- Quinn, T., Katz, N., Stadel, J., & Lake, G. 1997, astro-ph/9710043